Compact High-Intensity Crystal-Driven Neutron Source

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Active neutron interrogation is a promising technique for identification of threats such as explosives or shielded nuclear material. Neutrons are generated from fusion reactions when ions of appropriate species and energy impinge upon a target of a specific material having adequate cross-section to yield a neutron. For example the d(D,n), or d(T,n) reactions can be facilitated by deuteron beams hitting a deuterated or tritiated target, respectively. Accelerator-based technologies are rather large, and include large high-voltage power supplies. A crystal-driven neutron source offers a means to compact the high-voltage power supply, ion source, and accelerator structure in an integrated design one to two orders of magnitude smaller than alternative sources having similar neutron yields.

Pyrofusion has been demonstrated in recent years using pyroelectric crystals that generate large surface charge and voltages when subjected to thermal ramping. This effect is illustrated in Fig. 1. In this case, a tungsten needle of sufficient length and tip diameter is positioned on the positively charged surface of the crystal. As the charge and voltage build up during thermal ramping, the electric field intensifies at the radius of curvature of the needle tip until it becomes sufficient to cause field ionization of background deuterium molecules (3 mTorr) in proximity to the crystal surface. Once ionized, the deuterons are accelerated away from the positively charged high-voltage surface of the crystal.

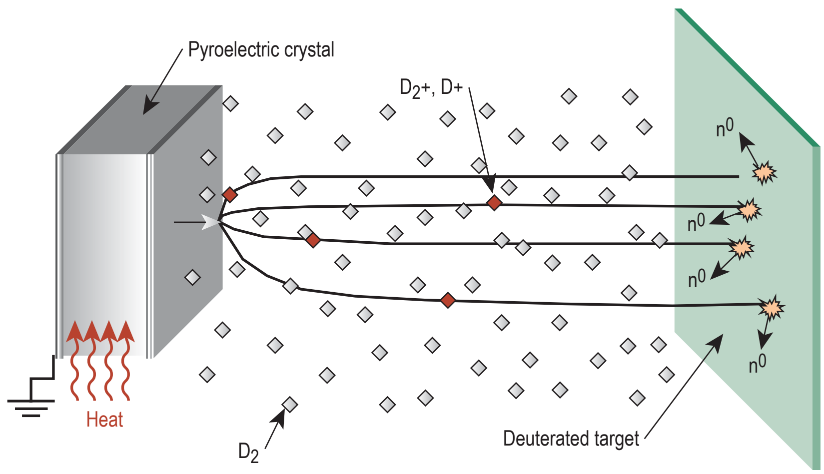
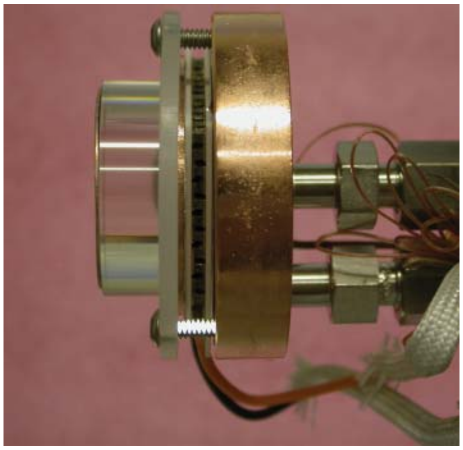


Figure 1. Illustration of pyrofusion effect.

Project Goals

The objective of this project is to provide a comprehensive understanding of the operation and limitations of pyrofusion as a means of generating neutrons in applications for identifying potential threats. As such, a compact (<1 liter), high-intensity (>10^7 n/s) source is desired for rapid detection of hidden or shielded materials of concern. The goal of this effort is to demonstrate neutron yields in excess of 10^6 n/s using the d(T,n) fusion reactions. The targeted problems include effective generation and control of deuteron ion beams, stable generation of acceleration voltages in the 100 to 200 kV range, and system integration and scaling.

Figure 2. Pyroelectric crystal mounting assembly including thermal control element.



Relevance to LLNL Mission

Active neutron interrogation is becoming a key approach for the detection and screening of hidden threats including explosives and shielded nuclear materials. This results from the penetrating nature of fast neutrons and subsequent specificity of the resulting gammas produced through inelastic scattering and capture of the neutrons from materials exposed to the neutrons. As such, this technology will make a significant impact for applications in homeland security, the military, and intelligence gathering needs. Furthermore, it has the potential

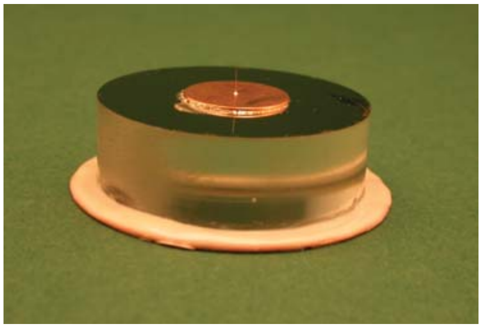


Figure 3. Pryoelectric crystal mounted with arc suppression dielectric guard ring at base of assembly.

to provide new methods of interrogation that are not presently possible due to the nature of existing neutron sources. In this sense, a crystal-driven neutron source represents a new paradigm for active interrogation of threats..

FY2007 Accomplishments and Results

We have made significant progress on experimental efforts to understand the limits of pyrofusion for specified configurations, and further extend these limits to useful operational regimes. The key contributions to the field have been the design and assembly of a precision thermal control assembly for crystal actuation and thermal cycling; high-voltage engineering designs implemented to suppress high electric fields that result in electron cascading and subsequent breakdown events; and demonstration of record neutron yields using ungated, crystal-driven field ionization sources.

Figure 2 illustrates the crystal mounting assembly, which incorporates a thermal electric element for rapid heating and cooling of the crystal. Figure 3 shows a $LiTaO_3$ crystal (1 cm thick by 3 cm diameter) with a dielectric guard ring formed around the base to suppress flashover at the base electrode and crystal interface where high electric fields build up during thermal ramping. This has resulted in significant improvement in reproducing the ion beams for each thermal cycle. Figure 4 illustrates the ion beam current, and subsequent neutrons generated during a single thermal cycle. In this experiment, a deuterated target (ErD2) was placed in series with a Faraday cup to simultaneously measure the ion beam while generating neutrons. A He3 scintillator detector was used to measure the neutron yield. Figure 5 shows the x-ray spectra measured during the crystal thermal cycle, which provides a measure of the voltage that the crystal is charged to, in this case >80 kV. Incorporating active thermal control, these results have demonstrated >2 times the neutron yields produced by other groups using this technique. This is mainly due to the precision thermal control, along with the arc suppression approaches that enable long, persistent ion beams generated from a single thermal cycle.

Related References

1. Naranjo, Gimzewski, and Putterman, *Nature*, **434**, 28, pp. 1115-1117, April 2005.
2. Geuther and Danon, *J. Appl. Phys*., **97**, 074109, 2005.
3. Geuther, Danon, and Saglime, *Phys. Rev. Lett*., **96**, 5, pp. 054803-1-4, February 10, 2006.

FY2008 Proposed Work

During FY2008 efforts will focus on the inverse configuration in which the target is mounted on the high-voltage surface of the crystal. This configuration has the advantage that the ion beam will be better focused on target without the need for focusing optics due to the electric field distribution. Additional efforts will continue the development of a gated ion source that will decouple field ionization from the crystal charge state, providing a separate, low voltage (<500 V) power supply for either pulsed or DC ion beam operation.

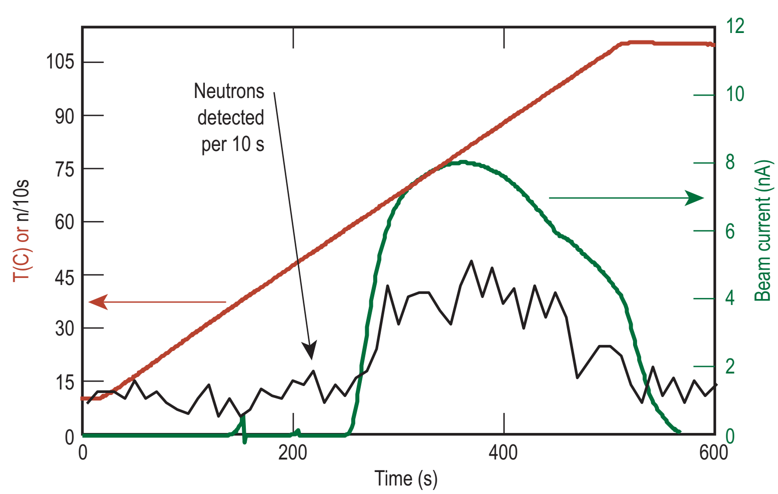


Figure 4. Crystal-generated ion beam and resulting neutron yield during thermal ramping cycle.

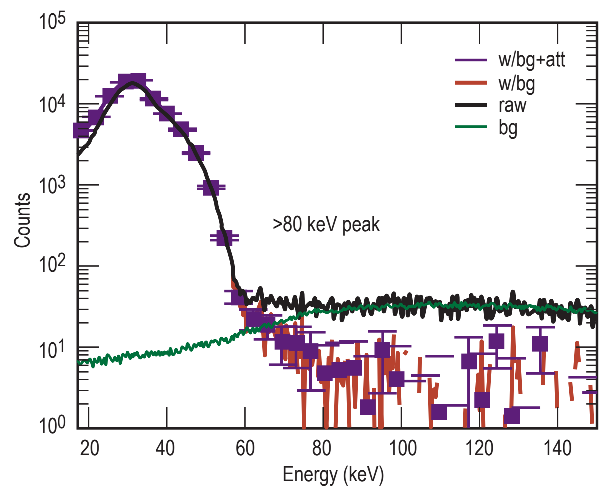


Figure 5. Resulting x-ray spectra generated during ion beam measurements indicating a crystal voltage on the order of >80 kV achieved during thermal ramping.